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A three-loop neutrino model with global $U(1)$ symmetry

Hisaki Hatanaka [a], Kenji Nishiwaki [a], Hiroshi Okada [a], Yuta Orikasa [a,b,*]

[a] *School of Physics, KIAS, Seoul 130-722, Republic of Korea*
[b] *Department of Physics and Astronomy, Seoul National University, Seoul 151-742, Republic of Korea*

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Abstract

We study a three-loop induced neutrino model with a global $U(1)$ symmetry at TeV scale, in which we naturally accommodate a bosonic dark matter candidate. We discuss the allowed regions of masses and quartic couplings for charged scalar bosons as well as the dark matter mass on the analogy of the original Zee–Babu model, and show the difference between them. We also discuss that the possibility of the collider searches in a future like-sign electron liner collider could be promising.

1. Introduction

Even after the discovery of the Higgs boson, the large Yukawa hierarchy required by the observed values of the fermion masses remains to be one of the unnatural issues in the Standard Model (SM). The situations get to be more serious in the neutrino sector since their corresponding values are sub-eV, which means that we have to realize at least $\mathcal{O}(10^{11})$-magnitude hierarchy by hand when we adapt the Dirac-type mass terms for explanation. An elegant way for alleviating

* Corresponding author at: School of Physics, KIAS, Seoul 130-722, Republic of Korea.
E-mail addresses: hatanaka@kias.re.kr (H. Hatanaka), nishiken@kias.re.kr (K. Nishiwaki), hokada@kias.re.kr (H. Okada), orikasa@kias.re.kr (Y. Orikasa).

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Table 1
Contents of lepton and scalar fields and their charge assignment under $SU(2)_L \times U(1)_Y \times U(1) \times \mathbb{Z}_2$, where $x \neq 0$.

	Lepton fields		Scalar fields					
	L_L	e_R	Φ	Σ_0	h_1^+	h_2^+	k^{++}	χ_0
$SU(2)_L$	**2**	**1**	**2**	**1**	**1**	**1**	**1**	**1**
$U(1)_Y$	$-1/2$	-1	$1/2$	0	1	1	2	0
$U(1)$	$-x$	$-x$	0	x	$2x$	x	$2x$	$-x$
$\mathbb{Z}_2$	$+$	$+$	$+$	$+$	$+$	$-$	$+$	$-$

the unnaturalness is making the situation that the neutrino masses are loop-induced as initiated by A. Zee at one-loop level in Ref. [1].

In such a setting, loop factors naturally reduce their mass values and we can explain the minuscule neutrino masses with less fine-tuned Yukawa couplings. This mechanism is fascinating and lots of works have been done in this direction [1–73]. As a naive expectation, higher-loop generated neutrino masses would be preferable because much more improvement could be expected due to a large amount of loop factors. Several three-loop models have been proposed already, e.g., in Refs. [4,10,33,55,48]. In higher-loop models, a dark matter (DM) candidate tends to propagate inside the loop, whose stability is naturally ensured by symmetries for prohibiting lower-level neutrino masses. Also, when a continuous global symmetry is used in such a model, we would predict a Nambu–Goldstone boson (NGB). This kind of particles could play a significant role in an early stage of the Universe [74].

In this paper, we propose a model as a simple extension of the Zee–Babu model [3] with two-loop induced neutrino mass terms, by adding an additional singly-charged gauge singlet scalar and DM to the original one, where the radiative neutrino mass terms turn out to appear at the three-loop level. Note that a doubly-charged scalar ($k^{\pm\pm}$) and a singly-charged singlet scalar ($h^{\pm}$) are introduced in the Zee–Babu model [3]. Our model overcomes a shortcoming in the Zee–Babu model of the absence of DM candidate. On the other hand, the structure of the internal loops within the radiative neutrino masses gets to be morphed. Therefore, expected mass ranges of the charged particles are affected from the original ones.

This paper is organized as follows. In Section 2, we explain the construction of our model and analyze the system with declaring brief prospects in collider-related issues. We summarize and conclude in Section 3.

2. Discussions on our model

2.1. Model setup

We discuss a three-loop induced radiative neutrino model. The particle contents and their charges are shown in Table 1. We add new bosons, which are, two $SU(2)_L$ singlet neutral bosons (Σ_0, χ_0), two singly-charged singlet scalars (h_1^+, h_2^+), and one $SU(2)_L$ singlet doubly-charged boson k^{++} to the SM. We assume that only the SM-like Higgs Φ and Σ_0 have vacuum expectation values (VEVs), which are symbolized by $\langle\Phi\rangle \equiv v/\sqrt{2}$ and $\langle\Sigma_0\rangle \equiv v'/\sqrt{2}$, respectively. x ($\neq 0$) is an arbitrary number of the charge of the global $U(1)$ symmetry,[1] and the assignments

[1] This symmetry cannot be gauged because its anomaly cannot be canceled.